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Atmospheric Scintillation Effects on Electromagnetic Weapons

R W McMillan
US Army Space and Missile Defense Command
PO box 1500, Huntsville, AL 35807-3801

ABSTRACT

Atmospheric turbulence has been shown to cause measurable effects on the propagation of electromagnetic radiation. These effects are significant at both visible/IR and microwave and millimeter wavelengths even though they vary as $f^{7/6}$, where f is frequency. The contribution of the humidity structure function C_Q^2 makes these effects significant for many applications in most wavebands of interest. In this paper we present results of calculations of the effects of atmospheric turbulence on electromagnetic signals propagated through the turbulent atmosphere with application to the use of an electromagnetic weapon to destroy an enemy sensor.

1. INTRODUCTION

Atmospheric turbulence manifests itself in many ways in electromagnetic propagation. The most common effect is that of intensity fluctuations commonly observed in many readily observable situations, such as the twinkling of stars [1]. It is this manifestation that is considered in this paper. Other effects are phase fluctuations that result in scintillation of the angle of arrival of a beam. Still others result in thermal blooming and related phenomena. Many workers in this field did not consider the possibility that turbulence would affect propagation at the longer wavelengths because of the $f^{7/6}$ dependence mentioned above. This strong dependence on frequency is compensated to some extent by the fact that the atmospheric index of refraction structure parameter C_n^2 is dependent not only on the temperature structure parameter C_T^2, but also on both the humidity structure parameter C_Q^2 and the cross correlation of the temperature and humidity C_{TQ} [2]. The humidity structure function dominates at microwave and millimeter wavelengths, and the temperature structure parameter dominates at visible and infrared wavelengths. The cross correlation of these parameters can usually have either a positive or negative sign, depending on time of day.

2. THEORY

For the case treated in this paper, the size of the electromagnetic beam is assumed to be much larger than the size of the aperture of the sensor, a restriction that is generally met for microwave or millimeter-wave weapons but may not be true for laser weapons, which are usually focused on the target to give higher power density. This situation is shown in Figure 1. Note that if the target were large enough, or if all of the radiation were focused on the target, it would collect all of the incident energy, regardless of the magnitude of the fluctuations. This phenomenon is called aperture averaging [1]. We also assume that the time duration of the transmitted signal is short compared to the time required for the atmospheric turbulence statistics to change. Both of these conditions are generally met for microwave or millimeter-wave weapons.

Since the energy in an electromagnetic beam cross section is log normally distributed, the probability that the energy at a small point in the beam corresponding to the location of the target is between E and $E + dE$ is [3]

$$P(E)dE = \frac{1}{(2\pi)^{1/2}\sigma_E} \bullet \exp\left[-\frac{(\ln E - \ln E^*)^2}{2\sigma_E^2}\right] d(\ln E), \tag{1}$$

where σ_E is the log intensity variance of turbulence fluctuations and lnE^* is the mean of lnE. The probability $P(R)$ that the energy on target is equal to or less than some energy $E(R)$ required to disable the target is then

$$P(R) = \frac{1}{(2\pi)^{1/2}\sigma_E} \bullet \int_0^{E_R} \exp\left[-\frac{(\ln E - \ln E^*)^2}{2\sigma_E^2}\right] d(\ln E), \tag{2}$$

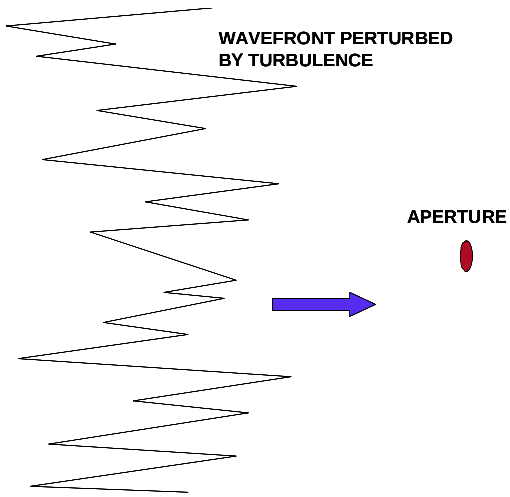

Figure 1. The wavefront of the electromagnetic source must be much larger than the size of the hostile aperture.

so that this latter equation is the probability that not enough energy density will be incident on the target to destroy it. Following [4] let

$$(\ln E - LnE^*)/\sqrt{2}\sigma_E = W, \quad \text{then} \qquad (3)$$

$$dW = d(\ln E)/\sqrt{2}\sigma_E, \qquad \text{and}$$

$$d(\ln E) = \sqrt{2}\sigma_E.$$

At $E = 0$, $W = -\infty$, and at $E = E_R$, $W = (\ln E_R - \ln E^*)/\sqrt{2}\sigma_E$.

Making the indicated substitutions and limit changes gives

$$P(R) = \frac{1}{\pi^{1/2}} \bullet \int_{-\infty}^{(\ln E_R - \ln E^*)/\sqrt{2}\sigma_E} \exp(-W^2)dW. \qquad (4)$$

The term *lnE** is defined to be the mean of lnE_R and is given by [5]

$$E^* = \overline{E}\exp(-\sigma_E^2/2), \qquad (5)$$

where $\bar{E}$ is the average value of E. Now let $\bar{E} = KE_R$, where K is some fraction of the energy required to kill the target, then

$$\ln E_R - \ln E^* = \ln E_R - \ln K - \ln E_R + \sigma_E^2/2 = \sigma_E^2/2 - \ln K, \qquad (6)$$

Substituting gives

$$P(R) = \frac{1}{\pi^{1/2}} \int_{-\infty}^{0} \exp(-W^2)dW + \frac{1}{\pi^{1/2}} \int_{0}^{1/\sqrt{2}(\sigma_E/2 - \ln K/\sigma_E^2} dW. \qquad (7)$$

The first integral gives simply ½, and the second is recognized to be

$$\frac{1}{2} erf\left[\frac{1}{\sqrt{2}}\left(\frac{\sigma_E}{2} - \frac{\ln K}{\sigma_E^2}\right)\right]. \qquad (\qquad (8)$$

Recall that *P(R)* is the probability that the required energy density will not be attained, so that the probability that the target will be killed is *1–P(R)*. The final result is

$$P_{kill} = 1 - \frac{1}{2}\left\{1 + erf\left[\frac{1}{\sqrt{2}}\left(\frac{\sigma_E}{2} - \frac{\ln K}{\sigma_E^2}\right)\right]\right\}. \qquad (9)$$

3. RESULTS

Figure 2 shows the results of calculating P_{kill} for values of σ_E equal to 0.1, 0.3, 0.6, and 1.0. These results show that severe atmospheric scintillation can result in a marked increase in the amount of energy required to disable an

enemy sensor. Another interesting result of this calculation evident from Figure 2 is that the probability of destroying the sensor is higher for heavy turbulence when the amount of energy transmitted is below that nominally required for sensor destruction. This apparent anomaly results from the probability that the sensor will be located at an instantaneous high peak on the transmitter wavefront. These peaks are higher and the valleys are lower for heavier turbulence.

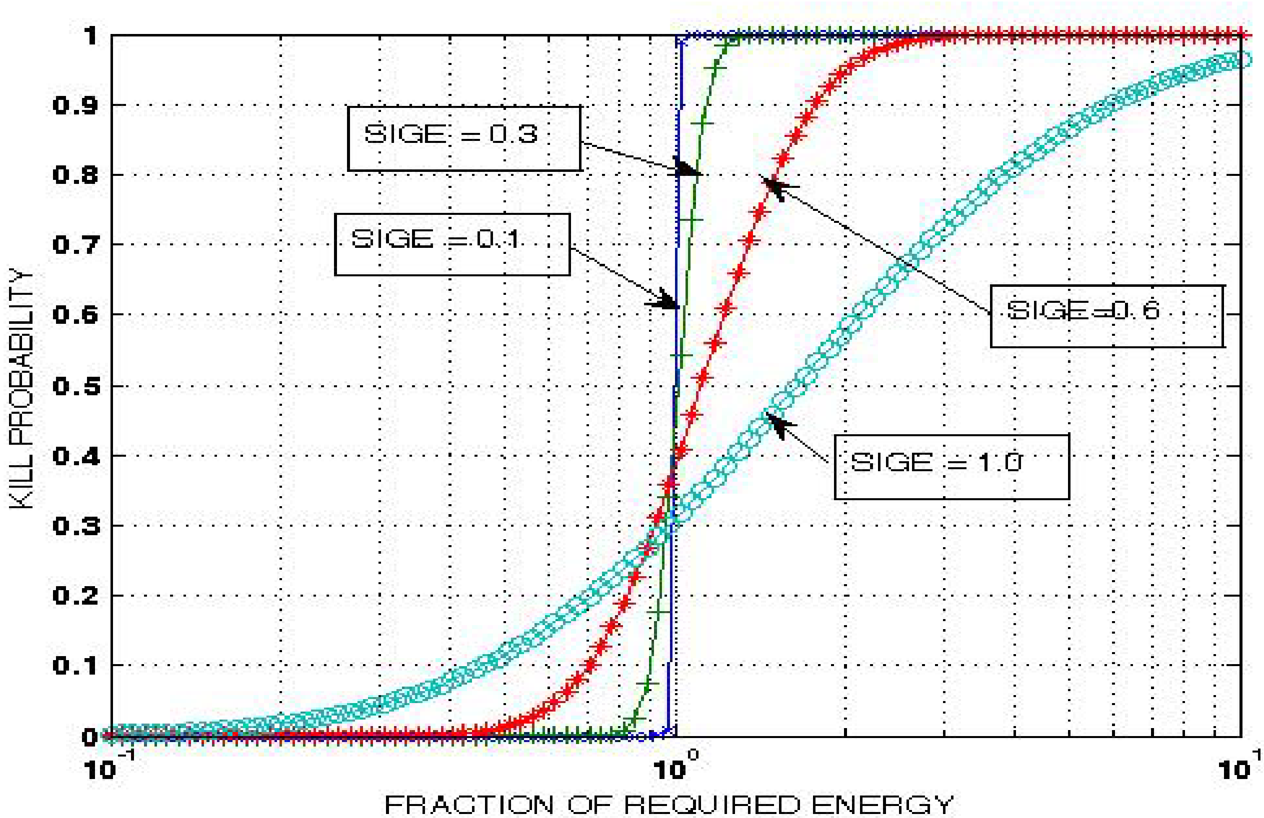

Figure 2. Results of calculating kill probability for several different values of the log intensity standard deviation

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